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(54) **DRIVER FOR PAGE TRANSITIONS IN AN ELECTRONIC PAPER DEVICE**

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G09G 3/34 (2006.01)

(52) **U.S. Cl.**

CPC ***G09G 3/344*** (2013.01); *G09G 3/2007* (2013.01); *G09G 2310/06* (2013.01); *G09G 2340/16* (2013.01)

(58) **Field of Classification Search**

CPC .. G09G 3/344; G09G 3/2007; G09G 2340/16

USPC 345/94, 107, 208, 545–551

See application file for complete search history.

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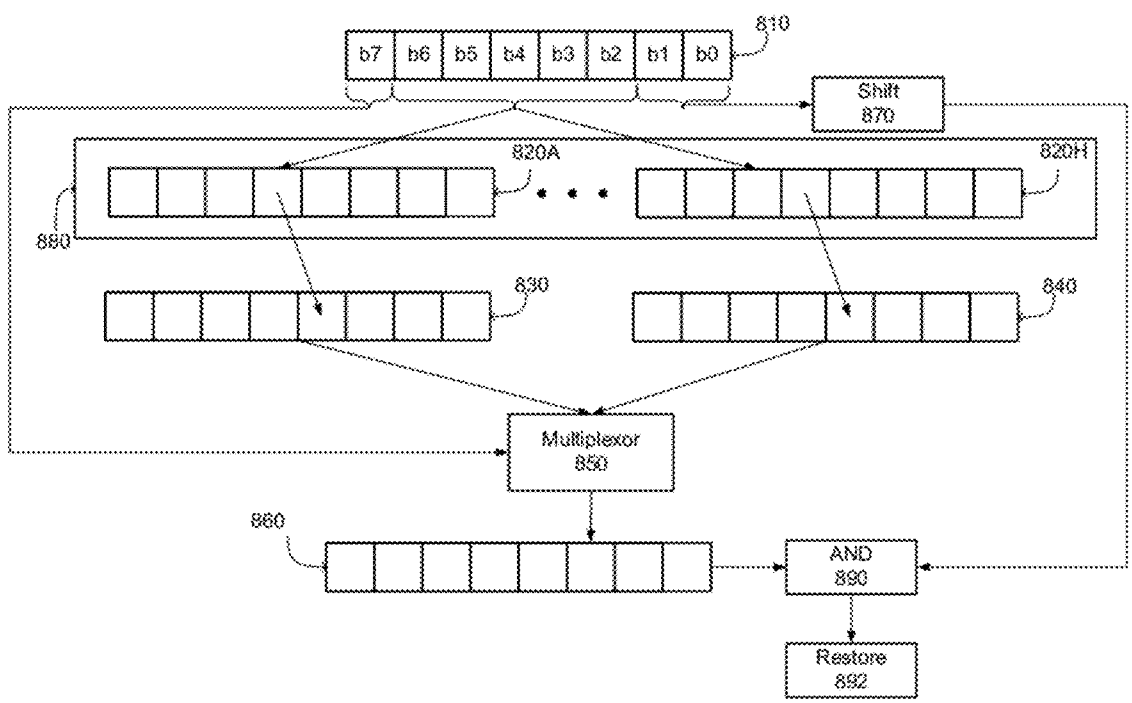
(57) **ABSTRACT**

A system and a method for updating an electronic paper display are disclosed. A memory includes a waveform table and a transition matrix including multiple pixels, each representing a pixel of the electronic paper display. A page transition display system is coupled to the memory and identifies waveforms from the waveform table associated with multiple transition matrix pixels by processing multiple transition matrix pixels in parallel. For example, the page transition display system loads multiple transition matrix pixels into a register and accesses the waveform table using the contents of the register. Using the identified waveforms, the page transition display system generates control signals used to modify the electronic paper device.

20 Claims, 8 Drawing Sheets



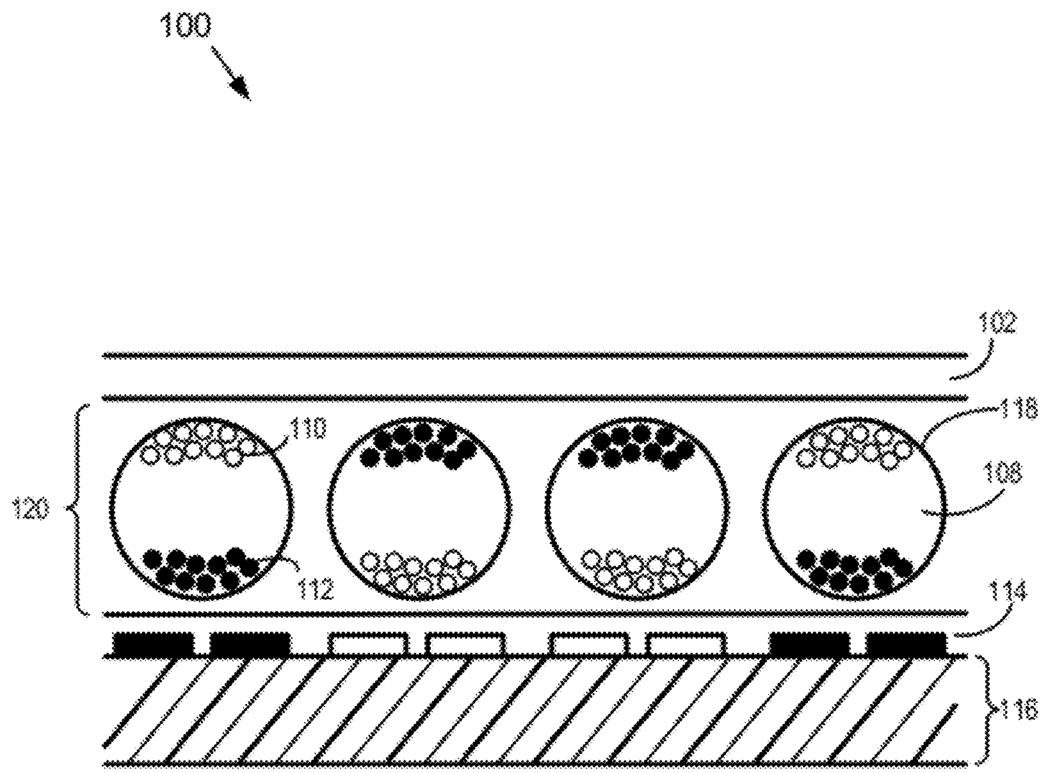


Figure 1

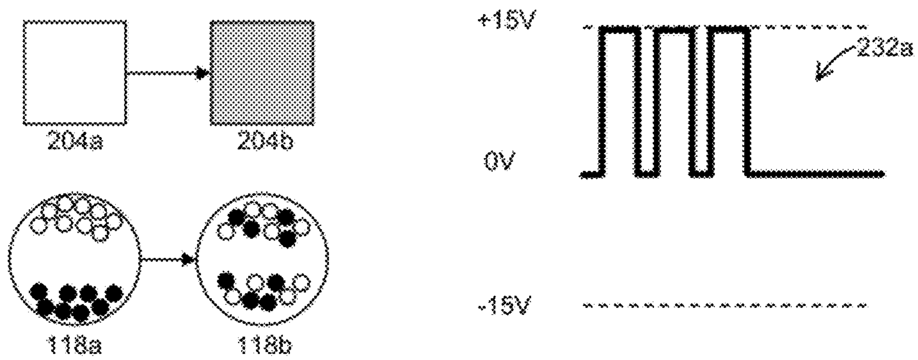


Figure 2A

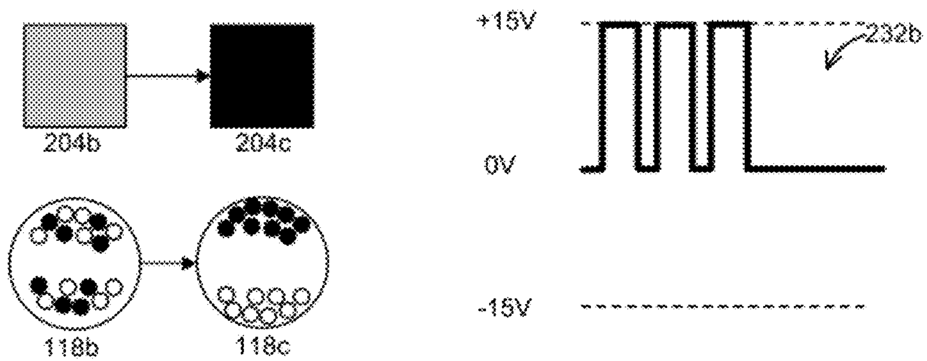


Figure 2B

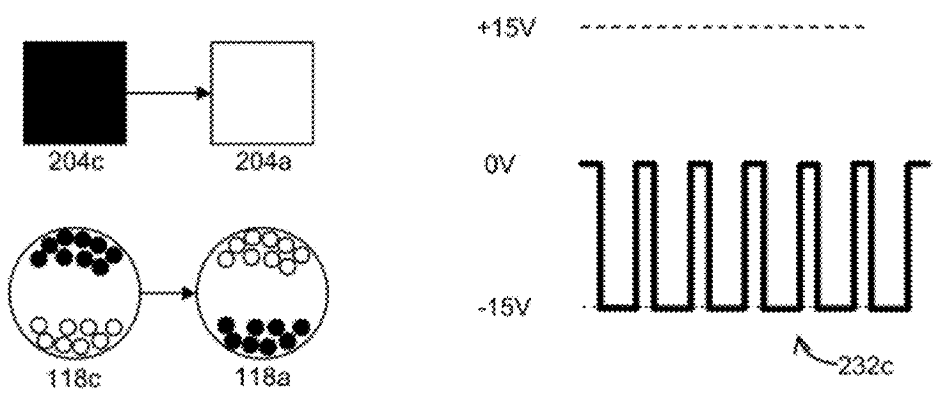


Figure 2C

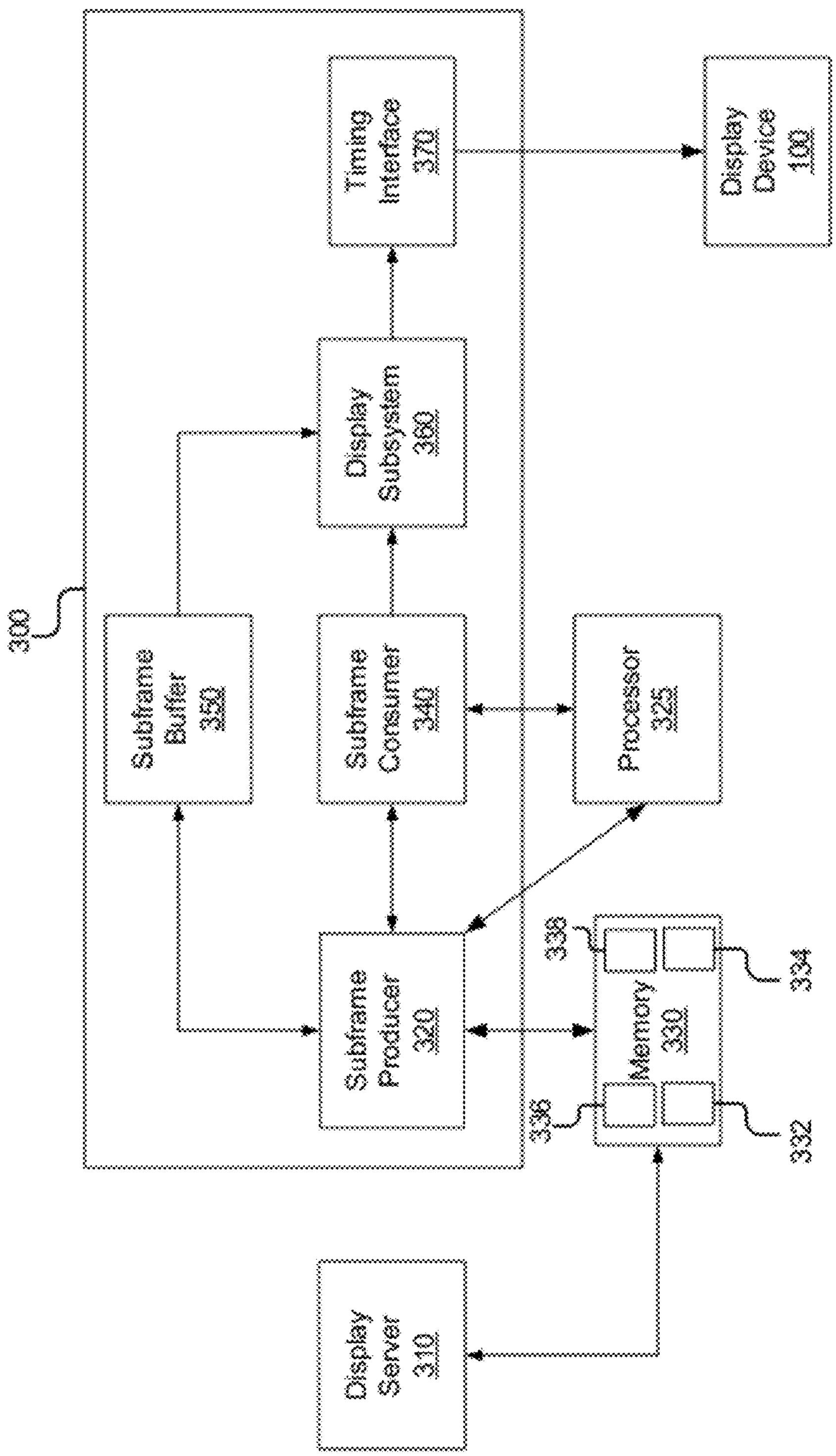

300
Timing Interface 370
Display Device 100
Display Subsystem 360
Subframe Buffer 350
Subframe Consumer 340
Processor 325
Subframe Producer 320
Memory 330
338
334
336
332
Display Server 310

Figure 3

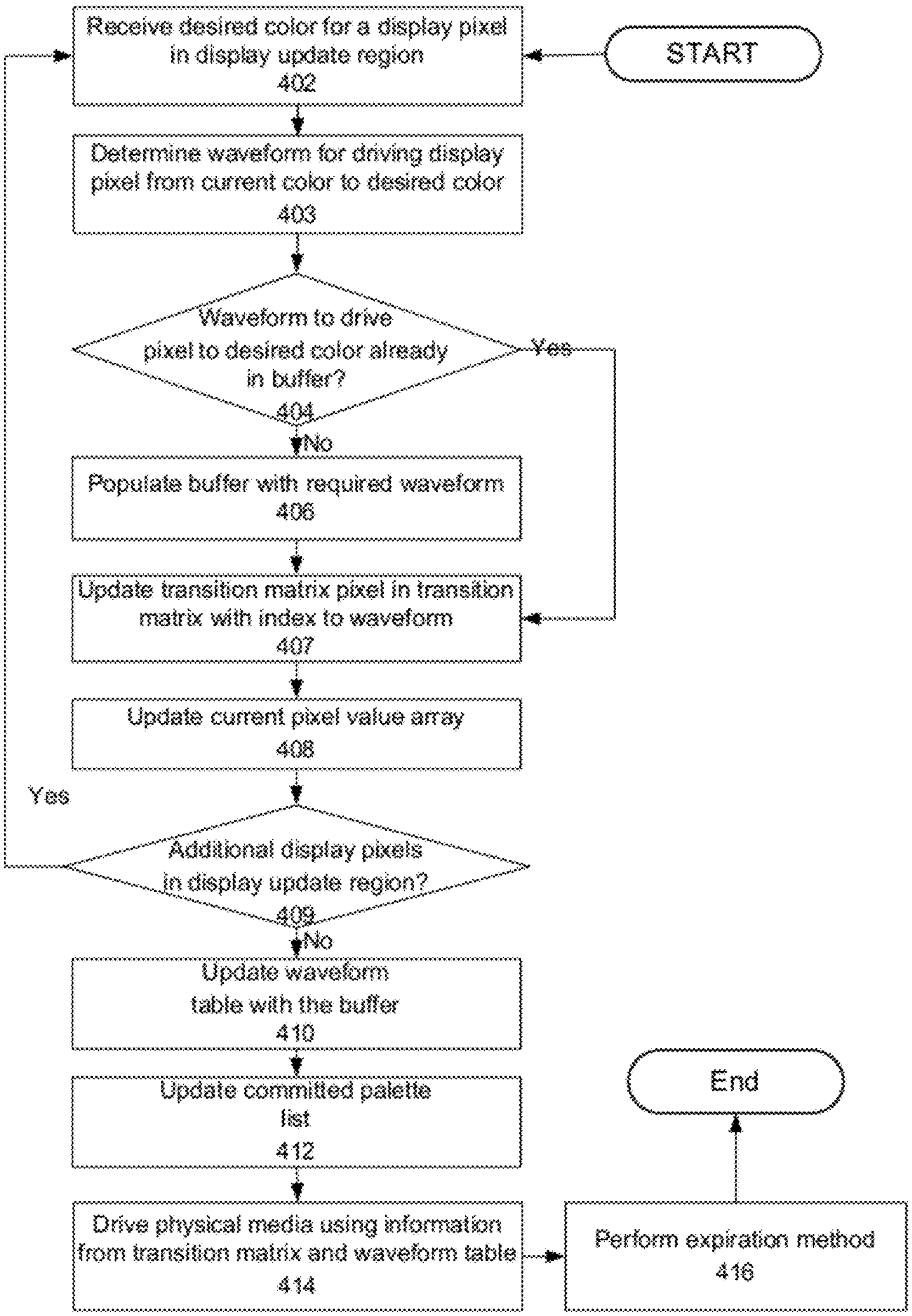

START
Receive desired color for a display pixel in display update region
402
Determine waveform for driving display pixel from current color to desired color
403
Waveform to drive pixel to desired color already in buffer?
404
Yes
No
Populate buffer with required waveform
406
Update transition matrix pixel in transition matrix with index to waveform
407
Update current pixel value array
408
Yes
Additional display pixels in display update region?
409
No
Update waveform table with the buffer
410
Update committed palette list
412
Drive physical media using information from transition matrix and waveform table
414
Perform expiration method
416
End

Figure 4

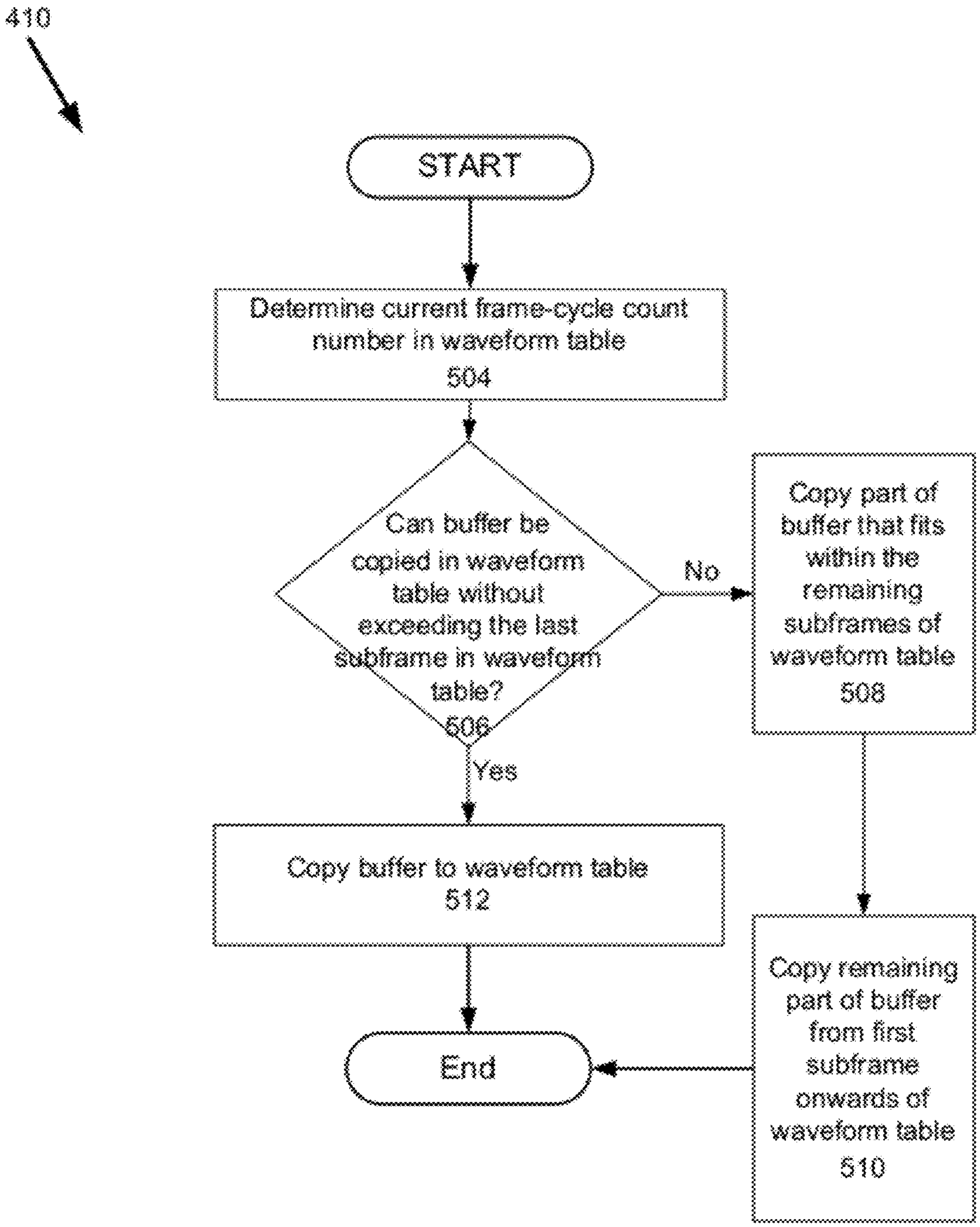

410
START
Determine current frame-cycle count number in waveform table
504
Can buffer be copied in waveform table without exceeding the last subframe in waveform table?
506
No
Copy part of buffer that fits within the remaining subframes of waveform table
508
Yes
Copy buffer to waveform table
512
Copy remaining part of buffer from first subframe onwards of waveform table
510
End

Figure 5

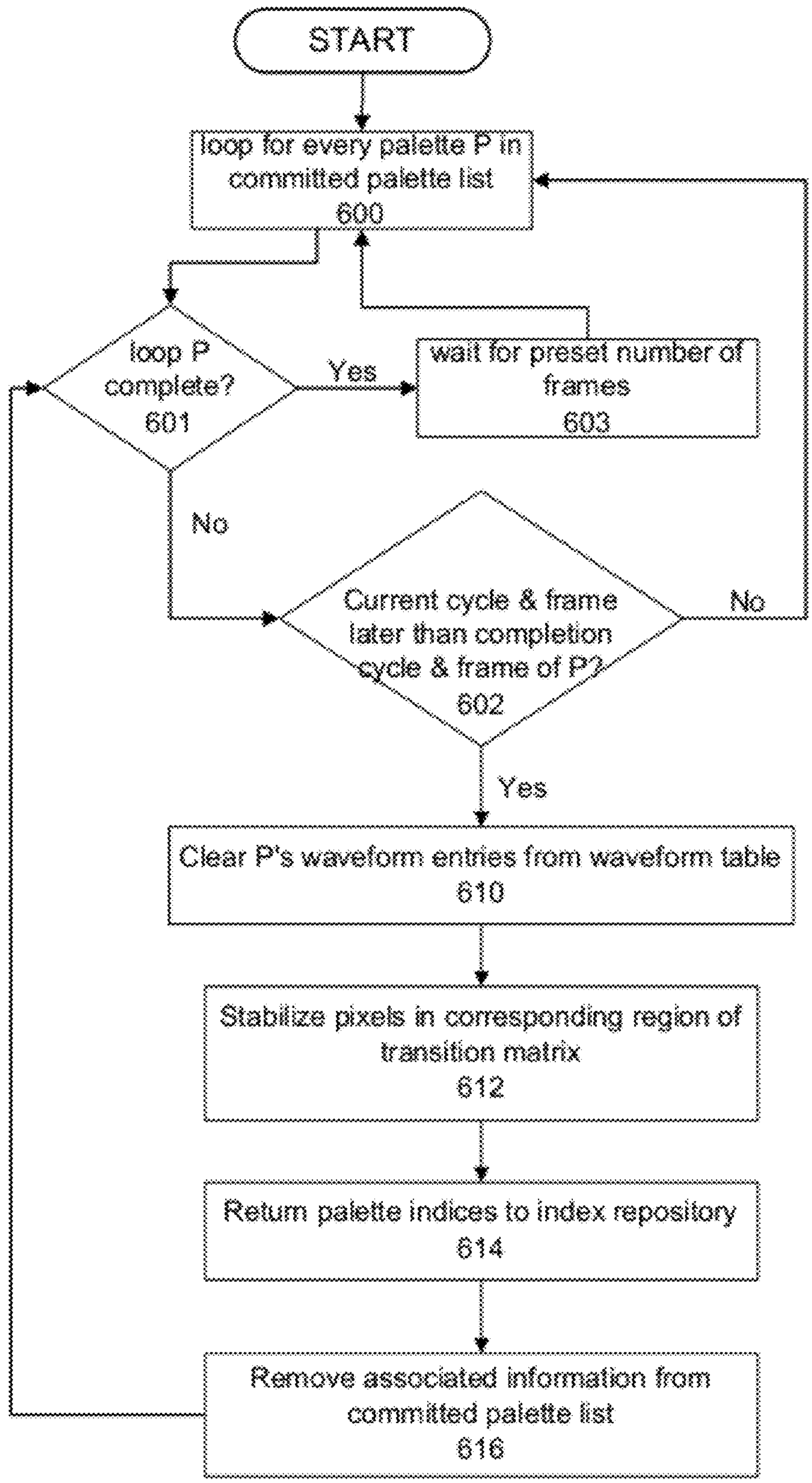

START
loop for every palette P in committed palette list
600
loop P complete?
601
Yes
wait for preset number of frames
603
No
Current cycle & frame later than completion cycle & frame of P?
602
No
Yes
Clear P's waveform entries from waveform table
610
Stabilize pixels in corresponding region of transition matrix
612
Return palette indices to index repository
614
Remove associated information from committed palette list
616

Figure 6

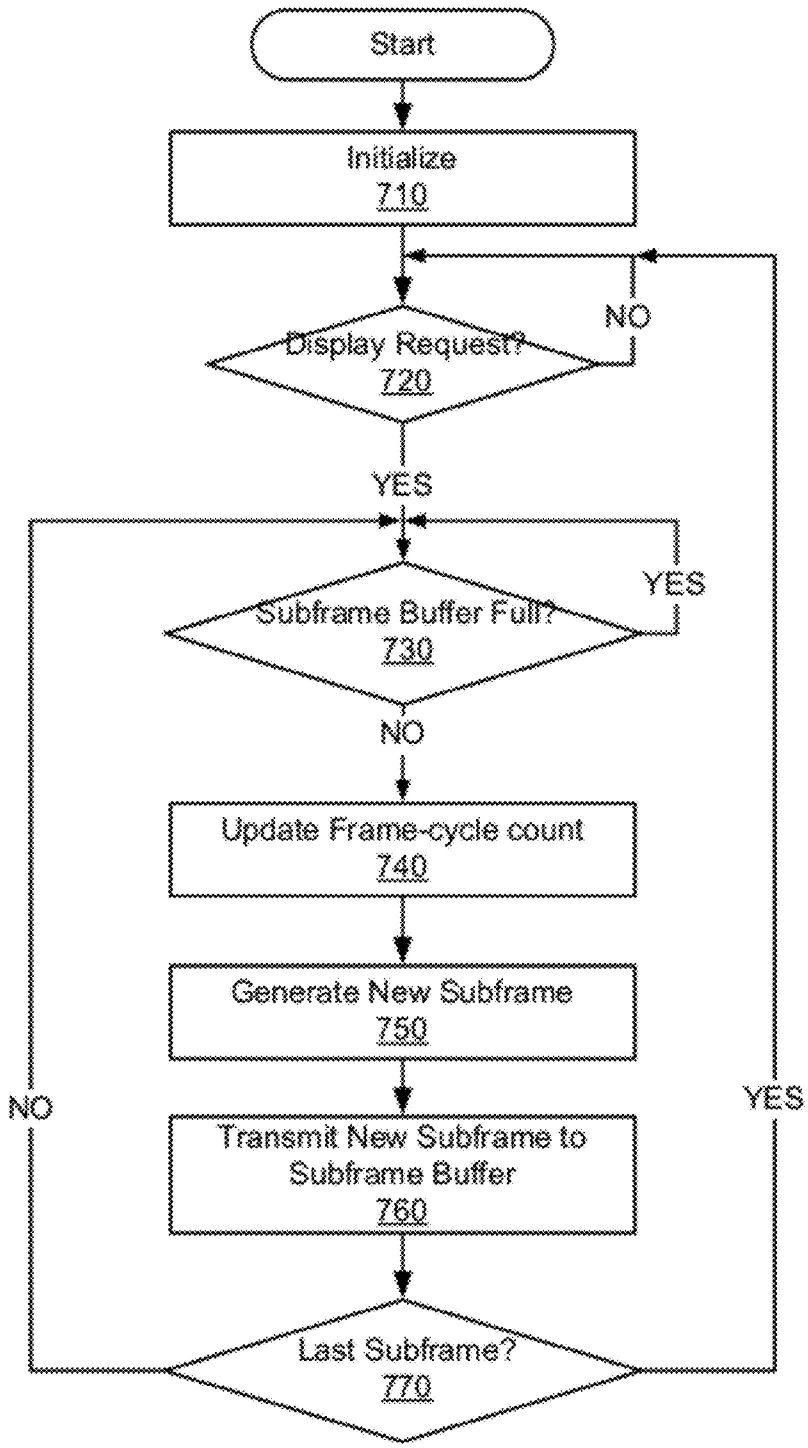

Start
Initialize
710
Display Request?
720
NO
YES
Subframe Buffer Full?
730
YES
NO
Update Frame-cycle count
740
Generate New Subframe
750
Transmit New Subframe to Subframe Buffer
760
Last Subframe?
770
NO
YES

Figure 7

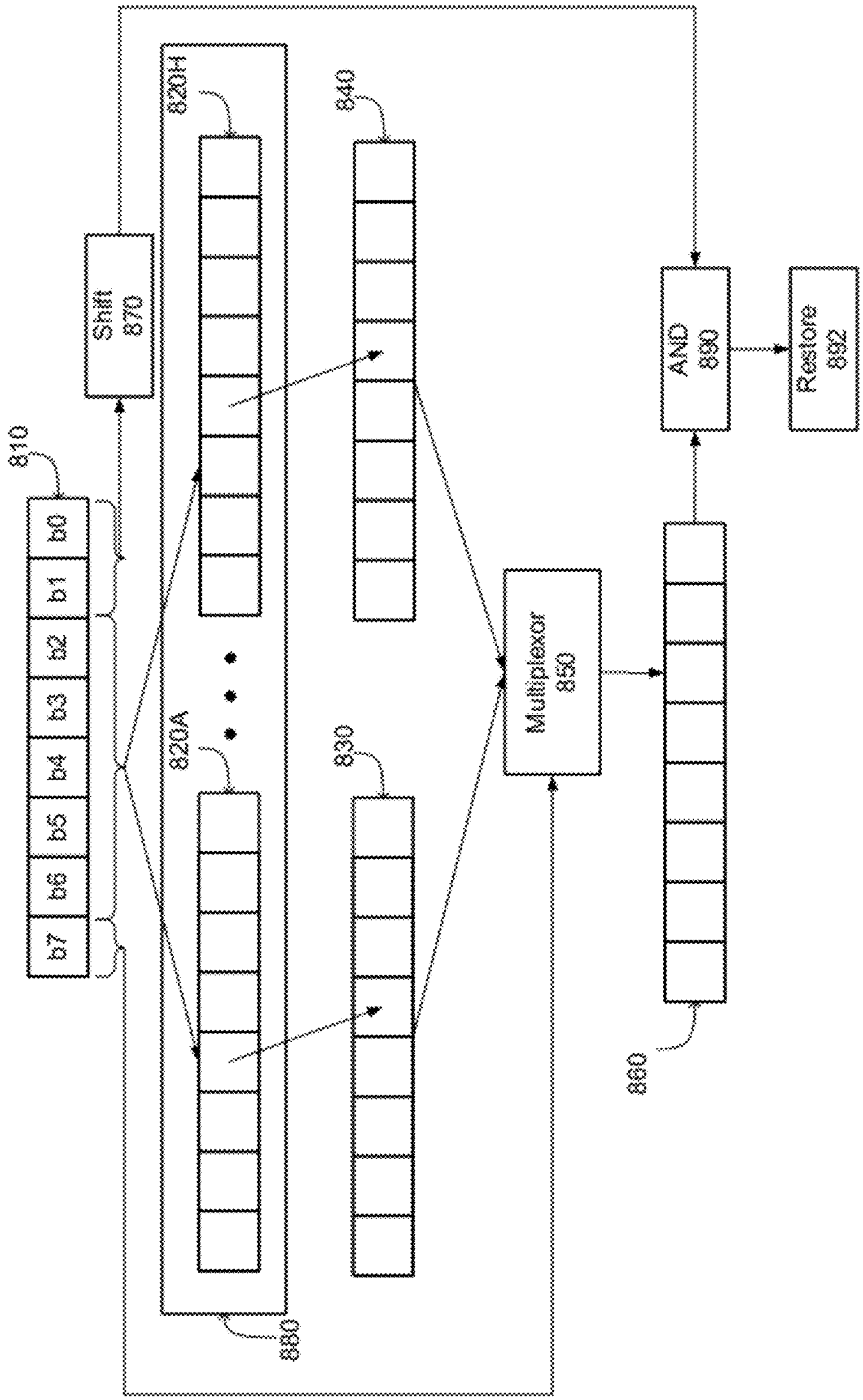

810
b0
b1
b2
b3
b4
b5
b6
b7
Shift
870
820H
820A
840
830
880
Multiplexor
850
AND
890
Restore
892
860

Figure 8

DRIVER FOR PAGE TRANSITIONS IN AN ELECTRONIC PAPER DEVICE

BACKGROUND OF THE INVENTION

1. Field of Art

The disclosure generally relates to the field of electronic paper displays, and more specifically relates to displaying a page transition on electronic paper displays.

2. Description of the Related Art

Several technologies have been introduced recently that provide some of the properties of paper in a display that can be updated electronically. Some of the desirable properties of paper that this type of display tries to achieve include: low power consumption, flexibility, wide viewing angle, low cost, light weight, high resolution, high contrast and readability indoors and outdoors. Because these types of displays attempt to mimic the characteristics of paper, they are referred to as electronic paper displays (EPDs) in this application. Other names for this type of display include: paper-like displays, zero power displays, e-paper and bi-stable displays.

A comparison of EPDs to Cathode Ray Tube (CRT) displays or Liquid Crystal Displays (LCDs) reveal that in general, EPDs require less power and have higher spatial resolution; however, many EPDs have lower update rates, less accurate color control and lower color resolution than LCDs or CRTs.

In a conventional LCD, the luminance, or color, of a pixel depends on the voltage applied to the pixel, with a given voltage corresponding to a specific luminance. In contrast, the luminance or color of a pixel in an EPD typically changes as voltage is applied to the pixel. For example, in some EPDs, applying a negative voltage to a pixel makes the pixel lighter (i.e., makes the pixel have a higher luminance) and applying a positive voltage makes the pixel darker. The higher the voltage and the longer or more frequently that voltage is applied, the larger the change in luminance. Hence, electronic paper displays are typically controlled by applying a sequence of voltages to a pixel instead of applying a single voltage to a pixel, like a typical LCD. Often, a sequence of voltages applied to an EPD pixel is referred to as a "waveform."

Additionally, control signals driving a pixel of an EPD also depend on the optical state to which the pixel is being driven and on the optical state from which the pixel is being driven. Other factors, such as temperature of the EPD, optical state of the pixel prior to the current optical state and the time since the pixel was last driven, are also taken into consideration when identifying a waveform to drive a pixel of an EPD.

Accordingly, conventional controllers for driving an EPD are often configured like an indexed color-mapped display. For example, a frame buffer of an electronic paper display includes indices to a waveform used to update an image rather than the waveform itself. When the optical state of a pixel is to be changed, the index of the appropriate waveform is chosen based on one or more factors, such as current pixel state and/or destination pixel state and the pixel's location in the frame buffer is set to the index corresponding to the chosen waveform.

It generally takes longer to apply a waveform to modify a pixel of an EPD than it does to modify a pixel of a conventional CRT or LCD display. This can lead to noticeable latency between when an application requests display of a new image on an EPD and when the EPD displays the new image. For example, an EPD using a conventional display controller may take 0.5 seconds to update a 1200×825 display. The latency can be reduced by simplifying the waveform calculation, for example by ignoring secondary factors such as dwell time and pixel history (prior displayed colors for the pixel) prior to the current optical state. However, but such simplifications to waveform calculation can result in remnants of prior displayed images remaining visible, a problem commonly referred to as "ghosting," when the EPD is modified.

While current update times are generally sufficient for the page turning needed by electronic books, they are problematic for interactive applications seeking to emulate page transitions or page flipping at higher speeds. A user may tolerate waiting for a second or two for transitioning between two pages when the user spends a few minutes reading each page. However, if a user wants to flip through numerous pages successively without spending more than a few seconds on each page, the increased latency of EPD modification becomes unacceptable.

SUMMARY OF THE INVENTION

The present invention overcomes the deficiencies and limitations of the prior art, at least in part, by a method for updating the display of an electronic paper device. In one embodiment, the system updating the electronic paper device comprises a memory storing a transition matrix and a waveform table. The transition matrix includes a plurality of transition matrix pixels. A page transition display system is coupled to the memory and identifies waveforms from the waveform table associated with a plurality of transition matrix pixels from the transition matrix. The page transition display system processes the plurality of transition matrix pixels from the transition matrix in parallel. For example the page transition display system applies one or more single instruction multiple data instructions to a plurality of transition matrix pixels to identify the waveforms associated with each of the plurality of transition matrix pixels in parallel. The page transition display system also generates control signals corresponding to the waveforms associated with the plurality of transition matrix pixels. In one embodiment, the control signals are communicated from the page transition display system memory buffer to a display subsystem that generates driving voltages based on the received control signals and applies the driving voltages to different pixels included in the electronic paper display device.

In one embodiment, the page transition display system comprises a subframe producer and a subframe consumer. The subframe producer is coupled to the memory and processes a plurality of transition matrix pixels in parallel to identify waveforms from the waveform table for modifying pixels in the electronic paper display device corresponding to transition matrix pixels. The subframe producer further generates a subframe associating an identified waveform with a corresponding transition matrix pixel. The subframe consumer is coupled to the subframe producer and controls a display subsystem that receives the subframe data from the subframe buffer.

The features and advantages described herein are not all-inclusive and many additional features and advantages will be apparent to one of ordinary skill in the art in view of the figures and description. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and not to limit the scope of the inventive subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is illustrated by way of example, and not by way of limitation in the figures of the accompanying drawings in which like reference numerals are used to refer to similar elements.

FIG. **1** is a cross-sectional view of a portion of an example electronic paper display.

FIGS. **2**A-**2**C are examples of modifying the optical state of one or more pixels in an electronic paper display.

FIG. **3** is a block diagram of a display system according to one embodiment of the present invention.

FIG. **4** is a flow chart of an embodiment of a method for driving one or more pixels of a display device according to one embodiment of the present invention.

FIG. **5** is a flow chart of an embodiment of method for transferring contents of the waveform buffer to the waveform table according to one embodiment of the present invention.

FIG. **6** is a flow chart of an embodiment of an expiration method performed by a display server according to one embodiment of the present invention.

FIG. **7** is a flowchart of a method for updating subframes for modifying a display device according to one embodiment of the invention.

FIG. **8** is a functional diagram of a method for identifying a waveform for application to an input pixel during a subframe according to one embodiment of the invention.

The Figures depict various embodiments of the present invention for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein.

DETAILED DESCRIPTION

A system and method for transitioning between pages using an electronic paper display (EPD) are described. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the invention. It will be apparent, however, to one skilled in the art that the invention can be practiced without these specific details. In other instances, structures and devices are shown in block diagram form in order to avoid obscuring the invention. For example, the present embodiment of invention is described in one embodiment below with reference to portable computing devices that are exemplified in a hardware and software platform using electronic paper, e-paper or electronic ink display. However, the present embodiment of invention applies to any type of portable computing device that can capture ink, data and commands, and send documents electronically.

Reference in the specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment. In particular the present embodiment of invention is described below in the content of two distinct architectures and some of the components are operable in both architectures while others are not.

Some portions of the detailed descriptions that follow are presented in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

The present embodiment of invention also relates to an apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, or it may comprise a general-purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, or any type of media suitable for storing electronic instructions, each coupled to a computer system bus.

The invention can take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment containing both hardware and software elements. In a preferred embodiment, the invention is implemented in software, which includes but is not limited to firmware, resident software, microcode, etc.

Furthermore, the invention can take the form of a computer program product accessible from a computer-usable or computer-readable medium providing program code for use by or in connection with a computer or any instruction execution system. For the purposes of this description, a computer-usable or computer readable medium can be any apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium. Examples of a computer-readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk-read only memory (CD-ROM), compact disk-read/write (CD-R/W) and DVD.

A data processing system suitable for storing and/or executing program code will include at least one processor coupled directly or indirectly to memory elements through a system bus. The memory elements can include local memory employed during actual execution of the program code, bulk storage, and cache memories which provide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution.

Input/output or I/O devices (including but not limited to keyboards, displays, pointing devices, etc.) can be coupled to the system either directly or through intervening I/O controllers.

Network adapters may also be coupled to the system to enable the data processing system to become coupled to other data processing systems or remote printers or storage devices through intervening private or public networks. Modems, cable modem and Ethernet cards are just a few of the currently available types of network adapters.

Finally, the algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general-purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these systems will appear from the description below. In addition, the present embodiment of invention is described with reference to a particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein.

Electronic Paper Device Overview

FIG. **1** illustrates a cross-sectional view of an example electronic paper display (EPD) **100**, also referred to herein as a "display device **100**." The EPD **100** comprises a transparent electrode **102** and a backplane **116** with a microcapsule layer **120** below the transparent electrode **102** and above the backplane **116**. The transparent electrode **102** is a thin layer of transparent material allowing a user to view microcapsules **118** included in the microcapsule layer **120**. In one embodiment, the top transparent electrode **102** also includes a transparent conductive material such as indium tin oxide.

In one embodiment, the microcapsule layer **120** includes closely packed microcapsules **118** that include a clear fluid **108**, such as a clear liquid polymer. A microcapsule includes first particles **112** and second particles **110** suspended in the clear fluid **108**. In one embodiment, the first particles **112** are black in color and the second particles **110** are white in color. Additionally, the first particles **112** have a first polarity and the second particles **112** have a second polarity. For example, a microcapsule **118** includes positively charged second particles **110** and negatively charged first particles **112**. As another example, a microcapsule **118** includes positively charged first particles **112** and negatively charged second particles **110**.

The electrode layer **114** is located below the microcapsule layer **120** and below the transparent electrode **102**. The electrode layer **114** is a network of electrodes used to drive one or more microcapsules **118** to different optical states. For example, the electrodes apply waveforms to a microcapsule to change the color of the microcapsule **118**. The network of electrodes is coupled to display circuitry, such as a display subsystem **360** and a timing interface **370**, which modifies the appearance of pixels of the EPD by applying voltage to specific electrodes. In one embodiment, applying a negative charge to the electrode repels negatively charged first particles **112** in a microcapsule **118** away from the electrode layer **114** and toward the transparent electrode **102** and attracts positively charged second particles **110** in the microcapsule **118** to the electrode layer **114**; if the first particles **112** have a black color and the second particles **110** have a white color, this gives a pixel including the microcapsule **118** a black appearance. In the preceding example, applying a positive voltage to the electrode repels positively charged second particles **110** in a microcapsule **118** away from the electrode layer **114** and toward the transparent electrode **102** and attracts negatively charged first particles **112** in the microcapsule **118** to the electrode layer **114**; if the first particles **112** have a black color and the second particles **110** have a white color, this gives a pixel including the microcapsule **118** a white appearance. Thus, the luminance of a pixel in an EPD **100** changes in response to the voltage applied to an electrode. In one embodiment, the amount of luminance change may depend on both the amount of voltage and the length of time for which it is applied, with zero voltage applied to an electrode leaving a pixel's luminance unchanged.

The microcapsules **118** included in the microcapsule layer **120** may be individually or collectively activated to a next optical state, such as black, white or gray. In some embodiments, the next optical state may be any other prescribed color. Different pixels associated with an electrode in the electrode layer **114** are associated with one or more microcapsules **118** included in the microcapsule layer **120**.

The electrode layer **114** is positioned on a surface of a backplane **116**, such as a plastic or ceramic backing layer. In other embodiments, the backplane **116** is a metal or glass backing layer. The electrode layer **114** includes an array of addressable pixel electrodes and supporting electronics. In one embodiment, the electrode layer **114** integrated with the backplane layer **116**.

FIGS. **2A-2C** are examples modification of the optical state of one or more pixels in an electronic paper display **100**. The examples of FIGS. **2A-2C** show movement of second particles **110** and first particles **112** in microcapsules **118** of an EPD **100** responsive to application of a waveform to an electrode. For purposes of illustration, FIGS. **2A-2C** display examples of waveforms **232***a-c* applied to one or more microcapsules **118** by an electrode, or electrodes, in the electrode layer **114**.

FIG. **2**A illustrates a change in position of second particles **110** and first particles **112** in microcapsule **118** when electrode layer **114** applies an example waveform **232***a* where +15 volts are applied to an electrode for three subframes. Application of the example waveform **232***a* causes a subset of positively charged particles, such as the first particles **112**, to move away from the electrode layer **114** and toward the transparent electrode **102**. Similarly, a subset of negatively charged particles, such as second particles **110**, move towards the positively charged electrode layer **114** and away from the transparent electrode **102** In one embodiment, the first particles **112** have a black color and the second particles **110** have a white color, so the movement of the first particles **112** and the second particles **110** causes a combination of first particles **112** and second particles **110** to be visible through the transparent electrode **102**, resulting in a gray color **204***b* for a corresponding pixel. As discussed above, a microcapsule **118** maintains this state, or the gray color **204***b* of FIG. **2**A, until another waveform is applied to an electrode proximate to the microcapsule **118**.

FIG. **2**B illustrates application of a second waveform **232***b* to the microcapsule **118** by an electrode in the electrode layer **114**. In the example of FIG. **2**B, the second waveform **232***b* is applied while the microcapsule **118** has a gray color **204***b*. In this example, the second waveform **232***b* applies +15 volts to the electrode for three subframes. This causes the remaining negatively charged second particles **110** to move towards the electrode layer **114** and the remaining positively charged first particles **112** to move towards the transparent electrode **102**. As a result, the majority, or all, of the positively charged first particles **112** are visible through the transparent electrode **102**. If the first particles **112** have a black color and the second particles **110** have a white color, the pixel color changes from gray **204***b* to black **204***c*.

FIG. **2**C illustrates application of a third waveform **232**c to the microcapsule **118** by an electrode in the electrode layer **114**. In the example of FIG. **2**C, the third waveform **232**c applies −15 volts to an electrode for six subframes and is applied while the microcapsule **118** is in the black state of FIG. **2**B. Application of the third waveform **232**c moves the majority, or all, of the positively charged first particles **112** toward the electrode layer **114** and moves the majority, or all, of the negatively charged second particles **110** toward the transparent electrode **102**. If the first particles **112** have a black color and the second particles **110** have a white color, the pixel color changes from black **204**c to white **204**a.

In the examples shown by FIGS. **2**A-2C, application of +15 volts to an electrode for six subframes changes a pixel color from white **204**a to black **204**c while application of −15 volts to an electrode for six subframes changes the pixel color from black **204**c to white **204**a. In some embodiments, the waveform used to change a pixel from a first color to a second color is not the polar opposite of the waveform used to change the pixel from the second color back to the first color. Additionally, while FIGS. **2**A-2C illustrate waveforms including positive voltages and zero voltages or including negative voltages and zero voltage, in other embodiments waveforms include any combination of positive voltages, negative voltages or zero voltage.

Additionally, the waveform subframes can each represent a time period, such as 20 milliseconds (ms). Accordingly, the time to change a pixel color from white **204**a to black **204**c is six subframes or 120 ms. This time is usually acceptable to a reader watching the transition of pixels as the user flips through pages on an electronic paper display. However, it typically takes longer to compute which voltage or waveform to apply to a pixel than it does to perform the corresponding operation on an EPD.

System Overview

FIG. **3** illustrates one embodiment of a page transition display system **300**. In the system shown in FIG. **3**, a display server **310** is coupled to the storage **312** and to a memory **330**. The page transition display system **300** is coupled to the memory **330**, a processor **325** and a display device **100**, such as an EPD. In one embodiment, the page transition display system **300** comprises a subframe producer **320**, a subframe buffer **350**, a subframe consumer **340**, a display subsystem and a timing interface **370**.

The display server **310** receives user input and identifies a document or other data for presentation by the display device **110**. For example, the display server **310** receives data identifying a document to be displayed from an application or from a user input. In one embodiment, the display server **310** receives a user input and determines a document, start page of the document from which the page transition starts, page transition speed and page transition direction. The display server **310** transmits the data to be displayed to the memory **330**. For example, responsive to receiving an input to transition from a first page to a second page, the display server **310** transmits data describing the page transition and the second page to the memory **330**.

The subframe producer **320** is communicatively coupled to a memory **330**. The memory **330** is a computer-readable storage device such as a random access memory, a flash memory, a hard drive or another suitable storage device. A waveform table **332** is included in the memory **330**. The waveform table **332** is an indexed storage for waveforms that are required to drive the display pixels on physical media **100** to desired colors. In one embodiment, the waveform table **332** is divided into a plurality of time periods represented by subframes and a cycle of waveform table **332** comprises subframes from first subframe to last subframe in waveform table **332**. A subframe includes a part of the waveform required to drive the display pixel to a desired color. In one embodiment, the waveform table **332** includes a current subframe and a cycle number. The current subframe is the subframe in the waveform table **332** that is being currently read by the subframe producer **320**. Similarly, the current cycle is the current cycle being read by the subframe producer **320**. After the subframe producer **320** has read a complete cycle, the subframe producer **320** starts reading the next cycle. In other words, the subframe producer **320** starts reading the waveform table **332** from the first subframe again.

The indices in waveform table **332** are not permanently committed to a particular waveform and the indices are updated repeatedly with different waveforms required to drive the display pixels of a region of the display device **100** to a desired color. After the waveforms stored in waveform table **332** have been used to drive the display pixels, those waveforms are removed from the waveform table **332** and their indices are later updated with waveforms required to drive display pixels in another region of the display device **100**. Indices that are not populated with a waveform in the waveform table **332** are assumed to correspond to a waveform consisting entirely of zeros, i.e. a waveform that specifies no change to a pixel during any subframe.

In one embodiment, the memory **330** also stores a transition matrix **334**, which is a storage including transition matrix pixels corresponding to pixels on the display device **100**. The display server **320** updates various transition matrix pixels of the transition matrix **334** with indices to waveforms required for driving the corresponding display pixels on the display device **100** to their desired color. The subframe producer **320** reads the transition matrix **334** to determine the index for a transition matrix pixel to determine an associated waveform from the waveform table **332**. The determined waveform is applied to the corresponding display pixel on the display device **100** by the display subsystem **360** to drive the display pixel to its desired color.

In one embodiment, the memory **330** includes a waveform buffer **336**, which is storage capable of storing a collection of indices and associated waveforms for driving one or more pixels in a region of the display device **100**. The display server **310** stores waveforms for driving one or more pixels in a region of the display device in the waveform buffer **336**. The display server **310** uses the information stored in the waveform buffer **336** to update the corresponding region of the transition matrix **334** with associated indices and to copy the waveforms and associated indices from the waveform buffer **336** and committed palette list **338**. The display server **310** can reuse an index and its associated waveform in the waveform buffer **336** for updating multiple transition matrix pixels in the transition matrix **334** if all of those transition matrix pixels require the same waveform to be driven to their respective desired colors. After the waveform and associated indices are copied, the waveform buffer **336** is used to store the next set of waveforms and associated indices for another update region.

The committed palette list **338**, included in the memory **330**, is a storage used to track the expiration of waveforms in waveform table **332** once the waveforms for a particular display update region have been used. One of ordinary skill in the art will understand that committed palette list **338** can store the list of committed palettes in numerous ways like list, stacks, arrays etc. The committed palette list **338** is populated by the display server **310**. The committed palette list **338** comprises a representation of one or more frame regions that are being updated, waveforms required to drive the display pixels in the display update region corresponding to the frame region, indices associated with the waveforms, and subframe and cycle number of the waveform table **332** at which the update to the display update region would be complete. Once the subframe producer **620** has generated control signals for applying the waveforms to the display device **100**, the display server **310** removes from the committed palette list **338** information associated with the display update region such as representation of the corresponding frame region, waveforms for the frame region, associated indices, and update completion subframe and cycle number.

The subframe producer **320** is communicatively coupled to the display server **310** and to the memory **330**. The subframe producer **320** accesses the memory **330** at a predetermined time interval to identify a waveform, or waveforms. In one embodiment, the subframe producer **320** identifies a waveform in parallel for application to each of the multiple pixels. For example, the subframe producer **320** applies one or more single instruction multiple-data (SIMD) instructions to process multiple input pixels as a vector to identify a waveform for each of the input pixels included in the vector. This parallel processing of multiple input pixels to identify waveforms in parallel is further described below in conjunction with FIG. **8** and operation of the subframe producer **320** is further described below in conjunction with FIG. **7**.

For example, the subframe producer **320** accesses the memory **330** at 20 ms intervals to identify waveforms applied to multiple pixels in the display device **100** to modify the pixels from a current state to a next state. Using the identified waveforms and a transition block **404** from the memory **330**, the subframe producer **320** generates subframes describing application of the identified waveforms to different pixels of the display device **100**. Hence, as the subframe producer **320** identifies waveforms for application to the display device **100**, subframes are generated and transmitted to the subframe buffer **350** for retrieval and application to the display device **100**. In one embodiment, a subframe generated by the subframe producer **320** describes voltages which are applied to different pixels in the display device **100** to modify the state of the different pixels.

In one embodiment, the subframe producer **320** comprises data encoded on a computer readable storage medium that, when executed by a processor **325**, causes the processor **325** to provide the functionality described herein. Thus, in one embodiment, the subframe producer **320** is a user space process executed by the processor **325**. Implementation as a user space process reduces the overall cost of the system **300** while also reducing the complexity of designing the system **300**. Additionally, implementing the subframe producer **320** as a process provides greater customization of how the display device **110** is controlled and simplifies modification of display device **110** control. Alternatively, the subframe producer **320** is a hardware device, such as an application specific integrated circuit (ASIC) or a field programmable gate array (FPGA).

The subframe buffer **350** is communicatively coupled to the subframe producer **320** and stores subframes received from the subframe producer **320**. The subframe buffer **350** is a computer readable storage device, such as a random access memory, a flash memory, a hard drive or another suitable storage device, that stores the subframes received from the producer **340**. Hence, the subframe buffer **350** includes the subframes identifying waveforms applied to different pixels of the display device **100** to modify the pixels of the display device **100**. By storing the subframes, the subframe buffer **350** allows the subframe producer **320** to more quickly begin determining an additional subframe while the display device **100** is updated using the subframe, or subframes, stored by the subframe buffer **350**. The subframe buffer **350** also expedites retrieval of a subframe by the subframe consumer **340** to expedite generation of control signals for modifying the display device **100**.

The subframe consumer **340** is communicatively coupled to the subframe buffer **350** and to the display subsystem **360**. The subframe consumer **340** controls the display subsystem **360**, which uses the subframes stored in the subframe buffer **350** to generate control signals that are applied to the display device **110**. In one embodiment, the control signals modify voltages of electrodes included in the display device to change the state of pixels of the display device **100**. For example, the control signals from the display subsystem **360** change the color of pixels included in the display device **100**. In one embodiment, the control signals from the display subsystem **360** modify the microcapsule layer **120** of an EPD, as described above in conjunction with FIGS. **1-2**C.

In one embodiment, the subframe consumer **340** is a kernel space process executed by the processor **325**. Implementation as a kernel space process reduces the overall cost of the system **300** while also reducing the complexity of designing the system **300**. Additionally, implementing the subframe consumer **340** as a process, such as a kernel space process, provides greater customization of how the display device **110** is controlled and simplifies modification of display device **110** control. Alternatively, the subframe consumer **340** is a hardware device, such as an application specific integrated circuit (ASIC) or a field programmable gate array (FPGA).

In on embodiment, a timing interface **370** is coupled to the display subsystem **360** and to the display device **100** to modify the timing with which the control signals from the display subsystem **360** are applied to the display device **100**. The timing interface **370** determines the timing of display device **110** modification and applies the voltages by performing operations specified by the display subsystem **360** at different times, allowing modification of the display device **100** as described above in conjunction with FIGS. **1-2**C.

Method Overview

FIG. **4** illustrates a flow chart describing the method used to drive one or more physical pixels in a display device **100** according to one embodiment of the invention. The display server **310** receives **402** the desired color for a display pixel in the display update region. Using the transition matrix pixel corresponding to the display pixel and the desired color for the display pixel, display server **310** determines a waveform to drive the display pixel from its current color to the desired color. In one embodiment, the display server **310** determines the current color for the display pixel from a stored array describing the current pixel value of multiple display pixels, retrieves or computes **403** the required waveform.

The display server **310** then determines **404** whether the required waveform is stored in a waveform buffer. For example the display server **320** determines **404** whether the computed required waveform has already been stored to the waveform buffer for another pixel. For the purposes of this determination, two waveforms are considered to be the same if they both comprise the same sequence of voltage pulses and both either interrupt the same waveform that is currently being driven or both do not interrupt another waveform. If the display server **610** has not already populated a waveform buffer with the same waveform for another pixel, the display server **610** populates **406** the waveform buffer with the required waveform and the index. Otherwise, the display server **610** skips populating the waveform buffer as the waveform is already stored in the waveform buffer.

Next, display server **310** updates **407** the transition matrix buffer pixel with index of the waveform in the waveform buffer and updates **408** a stored value associated with the display pixel to reflect the desired color. For example, the display server **310** determines updates a value in a stored array associated with the display pixel so that the desired color is associated with the display pixel. The display server **310** then determines **409** if multiple display pixels are being updated. For example, the display server **610** determines **409** if the display region being updated includes multiple display pixels. If multiple display pixels exist **609** in the display update region, steps **402**-**408** are repeated for those display pixels. If not, the display server **310** transfers **410** the waveforms from the waveform buffer **336** to corresponding indices in the waveform table **332**. One embodiment of this method is described in more detail below with reference to FIG. **5**.

When transferring **410** the waveform buffer to the waveform table **332**, the display server **310** executes a locking process to prevent the subframe producer **320** from reading the waveform table **332** while the display server **310** is writing data. For example, the display server **310** locks a mutex shared with the producer while transferring **410** data, transfers **410** the data and then releases the lock. The subframe producer **320** similarly obtains the shared lock before incrementing the frame-cycle count value.

In one embodiment, the display server **310** updates palette transfer module **408** then updates **412** the committed palette list **338** with contents of the waveform buffer, the subframe region corresponding to display update region and frame-cycle count of waveform table **332** at which the update will complete. The subframe producer **320** then sets a flag or other data to indicate that display updates are pending so that the display pixels on the display device **100** are modified using the indices from the transition matrix **334** and corresponding waveforms from waveform table **332**. After the update, the indices and corresponding waveforms expire and the display server **310** performs an expiration process, such as the one further described below in conjunction with FIG. **6**.

FIG. **5** illustrates one embodiment of a method for transferring **410** contents of the waveform buffer **336** to the waveform table **332**. The display server **310** determines **504** the current frame-cycle count in the waveform table **332** that is being read by the subframe producer **620**.

The display server **310** then determines **506** if the longest waveform in the waveform buffer **336** is shorter than the remaining subframes in the current cycle of the waveform table **332**. If the waveform buffer **336** includes an interrupting waveform, the display server **310** determines if the current frame in the waveform table **332** is already past the last subframe including pulses from the interrupted waveform. If yes, the display server **310** determines if the interrupting waveform would fit in the subframes remaining after the current subframe. If not, the display server **310** determines if the interrupting waveform would fit in the subframes remaining after the last subframe that includes the interrupting waveform.

If the longest waveform and the interrupting waveforms would fit into the current cycle, the display server **310** copies **512** waveforms from the waveform buffer **336** to the waveform table **332** starting at the subframe following the current subframe in the waveform table **332**. In one embodiment, waveforms that drive interrupted pixels are copied from the waveform buffer **336** to the waveform table **332** at the index of the interrupting waveform (that is, the index to which part of the interrupted waveform was previously copied). The interrupting waveform is copied starting either at the subframe following the current subframe or at the subframe following the last subframe of the copied region of the interrupted waveform, whichever is later.

In the case where the current subframe is the last subframe in the waveform table **332**, the following subframe is the first subframe of the waveform table **332**. If the longest waveform in the waveform buffer **336** is not shorter than the remaining subframes in the current cycle of the waveform table **332**, the display server **610** copies **508** parts of the waveforms to waveform table **332** starting at the subframe following current subframe until the last subframe in the current cycle of the waveform table **332**. In one embodiment, parts of waveforms that drive interrupted pixels are copied from the waveform buffer **336** to the waveform table **332** starting either at the subframe following the current subframe or at the subframe following the last subframe of the copied region of the interrupted waveform, whichever is later. The display server **310** copies **510** the remaining parts of the waveforms from the first subframe onwards of the next cycle of the waveform table **332**.

FIG. **6** illustrates one embodiment of an expiration method performed by the display server **310**. The display server **310** performs **600** a loop to examine each palette in the committed palette list **338**. If all palettes in the committed palette list **338** have been examined **601**, the display server **610** waits **603** for a preset period of time (typically on the order of a few subframes) and then repeats the loop over the palettes in the committed palette list **338**. Otherwise, the display server **310** determines **602** whether the subframe producer **320** has completed reading the subframes from waveform table **332** that include the longest waveform in the examined palette. In other words, the display server **310** determines **602** if the palette has expired. To do so, the display server **310** determines **602** whether the current subframe of the current cycle in waveform table **332** is later than the completion cycle and subframe for the examined palette. This will be true if either the current cycle in the waveform table **332** is greater than the completion cycle of the examined palette, or if the current cycle number in the waveform table **332** is equal to the completion cycle of the examined palette and the frame-cycle count in waveform table **332** is greater than the completion frame of the examined palette. If neither case is true, the display server **610** jumps back to the start of the loop **600** and examines the next palette in the completed palette list **338**. If the examined palette has expired, the display server **310** clears **610** the waveforms from waveform table **332** corresponding to the waveforms of the expired palette.

The display server **310** then stabilizes **612** the transition matrix pixels in the corresponding frame region. Next, the display server **310** returns **614** the indices associated with expired waveforms to a repository and removes **616** the information associated with the expired palette from the completed palette list **338**. The display server **310** then jumps back to the start of loop **800** and examines the next palette in the completed palette list **338**.

FIG. **7** illustrates one embodiment of a method of operation for a subframe producer **320**. The subframe producer **320** is first initialized **710** to a default state. In the default state, the subframe producer **320** determines **720** whether the display needs to be updated. In one embodiment, the subframe producer **320** determines **720** whether a display request has been received from an application **310** or another service. For example, the subframe producer **320** communicates with the display server **310** at predefined intervals to determine **720** if a display request has been received. If the display does not need to be updated, the subframe producer **320** continues to determine **720** whether the display needs updating. For example, if no display request has been received, the subframe producer **320** continues to monitor for display requests from the display server **310** or another service. In another embodiment, the subframe producer **320** determines whether a display request has been received by examining a location in memory shared between the subframe producer **320** and the display server **310**.

However, if the subframe producer **320** determines **720** that the display needs to be updated, the subframe producer **320** determines whether the subframe buffer **350** is full. For example, responsive to receiving a display request from an application **310** or other service, the subframe producer **320** accesses the subframe buffer **350** to determine **730** whether the subframe buffer **350** is full. If the subframe buffer **350** is full, the subframe producer **320** continues to access the subframe buffer **350** until it determines that the subframe buffer **350** is not full.

In response to determining **730** that the subframe buffer **350** is not full, the subframe producer **320** updates **740** a subframe counter to indicate that a new subframe is being added to the subframe buffer **350**. Meanwhile, the subframe producer **320** locks, increments, and unlocks the frame cycle count which is to be read by the display server **310**. After incrementing the subframe counter, the subframe producer **320** generates **750** a new subframe. In one embodiment, the subframe producer **320** generates **750** a new subframe by applying one or more instructions to multiple pixels, such as transition matrix pixels, from the transition matrix **334** to identify waveforms from the waveform table **332** corresponding to the different transition matrix pixels. For example, the subframe producer **320** applies one or more single instruction multiple-data (SIMD) instructions to a vector including a plurality of input pixels received from the transition matrix **334** to identify a waveform from the waveform table **332** associated with each of the plurality of input pixels included in the vector. One example of identifying a waveform associated with an input pixel is further described below in conjunction with FIG. **8**. Parallel identification of waveforms for a plurality of input pixels allows the subframe producer **320** to more rapidly generate **750** a new subframe.

The new subframe is transmitted **760** to the subframe buffer **350** for storage. After transmitting **760** the new subframe to the subframe buffer **350**, the subframe producer **320** determines **770** if the new subframe is the last subframe for updating the display for the current display request. If the new subframe is the last subframe, the subframe producer **320** resumes determining **720** whether to update the display. For example, the subframe producer **320** resumes determining **720** whether a display request is received from the application **310**. If the new subframe is not the last subframe, the subframe producer **320** again determines whether the subframe buffer **350** is full and steps **730**-**770** are repeated as described above.

FIG. **8** is a functional diagram of an example method for identifying a waveform associated with an input pixel. To simplify description, FIG. **8** shows waveform identification for a single input pixel. However, when implemented, the subframe producer **320** performs the steps described below in conjunction with FIG. **8** in parallel for multiple input pixels. For example, the subframe producer **320** performs the following actions in parallel for eight input pixels. Also, for purposes of illustration, FIG. **8** discusses an implementation where an input pixel is 8 bits; however, in other implementations, the input pixel can be a greater, or fewer, number of bits.

Initially, the subframe producer **320** loads multiple input pixels into an input register **810**. In the example of FIG. **8**, the subframe producer **320** loads eight input pixels into the input register **810**. In the example of FIG. **8**, each input pixel is 8 bits, so 8 bytes are initially loaded into the input register **810**. In the example of FIG. **8**, the data stored in the input register **810** is denoted as b**7**, b**6**, b**5**, b**4**, b**3**, b**2**, b**1** and b**0**, with b**7** indicating the most significant position of the input register **810** and b**0** is the least significant position of the input register **810**. The middle five positions of the input register **810**—b**6**, b**5**, b**4**, b**3** and b**2**—are communicated to a lookup table **880**. Hence, the input pixels stored in b**6**, b**5**, b**4**, b**3** and b**2** are communicated to the lookup table **880**.

In one embodiment, the lookup table **880** comprises registers **820**A-**820**H. The subframe producer **320** uses one or more subsets of the middle five positions of the input buffer **810** to identify data from registers **820**A-**820**H. In one embodiment, the subframe producer **320** identifies a first set of data from registers **820**A-**820**D using the middle five positions of the input buffer **810** and stores the first set of data in a first register **830**. The subframe producer **320** also identifies a second set of data from registers **820**E-**820**H using the middle five positions of the input buffer **810**. The second set of data identified from registers **820**E-**820**H is then stored in a second register **840**. Thus, a first set of data is identified using a subset of the input register **810** and a first portion of the lookup table **880**, registers **820**A-**820**D, and is stored in the first register **830** while a second set of data is identified using the subset of the input register **810** and a portion of the lookup table, registers **820**E-**820**H, and stored in the second register **840**.

The most significant position of the input register **810**, b**7** in the example of FIG. **8**, is communicated to a multiplexor **850**, such as a SIMD based multiplexing operator, coupled to the first register **830** and the second register **840**. Based on the most significant position of the input register **810**, the multiplexor **850** retrieves data form the first register **830** or from the second register **840** and stores the retrieved data in a holding register **860**. For example, if the most significant position, of the input register **810** has a logical high value, the multiplexor **850** communicates data from the first register **830** to the holding register **860**. In the above example, if the most significant position of the input register **810** has a logical low value, the multiplexor **850** communicates data from the second register **840** to the holding register **860**. While the example of FIG. **8** illustrates a 2:1 multiplexor **850** using the most significant position of the input register **810** to select an output, in other implementations the multiplexor **850** selects from a greater number of input using a greater amount of data from the input buffer **810**.

A masking operation is then applied to the holding register **860** to identify a subset of data from the holding register that identifies the waveform to be applied to the input pixel during a subframe. For example, the masking operation identifies two bits of output for each input pixel stored in the input register **810** from an eight bit holding register **860**. In the example of FIG. **7**, a bit shift operator **870** shifts the two least significant positions of the input register **810** in a specified manner. For example, the bit shift operator **870** left shifts the least significant positions of the input register **810** by two. The output of the bit shifter and the holding register **860** are then input to an AND operator **890** and the output of the AND operator **890** is restored **892** to identify the waveform for application to different input pixels during the subframe. In other embodiments, however, a different masking operation is performed to identify a waveform using a different subset of the holding register **860**.

The foregoing description of the embodiments of the present embodiment of invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the present embodiment of invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the present embodiment of invention be limited not by this detailed description, but rather by the claims of this application. As will be understood by those familiar with the art, the present embodiment of invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. Likewise, the particular naming and division of the modules, routines, features, attributes, methodologies and other aspects are not mandatory or significant, and the mechanisms that implement the present embodiment of invention or its features may have different names, divisions and/or formats. Furthermore, as will be apparent to one of ordinary skill in the relevant art, the modules, routines, features, attributes, methodologies and other aspects of the present embodiment of invention can be implemented as software, hardware, firmware or any combination of the three. Also, wherever a component, an example of which is a module, of the present embodiment of invention is implemented as software, the component can be implemented as a standalone program, as part of a larger program, as a plurality of separate programs, as a statically or dynamically linked library, as a kernel loadable module, as a device driver, and/or in every and any other way known now or in the future to those of ordinary skill in the art of computer programming. Additionally, the present embodiment of invention is in no way limited to implementation in any specific programming language, or for any specific operating system or environment. Accordingly, the disclosure of the present embodiment of invention is intended to be illustrative, but not limiting, of the scope of the present embodiment of invention, which is set forth in the following claims.

What is claimed is:

1. An electronic system for displaying pages on an electronic paper display device, the system comprising:

a memory storing a transition matrix and a waveform table, the transition matrix having a plurality of transition matrix pixels that represent a plurality of display pixels in the electronic paper display device; and

a page transition display system coupled to the memory, the page transition display system comprising:

a subframe producer configured to:

process the plurality of transition matrix pixels in parallel to identify one or more waveforms from the waveform table for modifying the plurality of display pixels in the electronic paper display device associated with the plurality of transition matrix pixels by:

loading the plurality of transition matrix pixels into a plurality of positions in an input register;

generating data in a holding register by selecting the data from a lookup table based on at least two subsets of the plurality of transition matrix pixels loaded at different positions in the input register; and

identifying the one or more waveforms from the waveform table using the data in the holding register; and

generate one or more subframes associating the one or more waveforms with the plurality of transition matrix pixels, each of the one or more subframes including a part of a waveform for driving one of the plurality of display pixels in the electronic paper display device; and

a subframe consumer configured to control a display subsystem that receives the one or more subframes from the subframe producer and generates control signals for the plurality of display pixels in the electronic paper display device corresponding to the plurality of transition matrix pixels using the identified waveforms.

2. The system of claim **1**, further comprising a display subsystem coupled to the page transition display system, the display subsystem configured to receive the control signals, generate driving voltages based on the received control signals and apply the driving voltages to the plurality of display pixels included in the electronic paper display device corresponding to the plurality of transition matrix pixels.

3. The system of claim **2**, further comprising:

a timing interface coupled to the display subsystem and to the electronic paper display device, the timing interface configured to receive the driving voltages from the display subsystem and determine a time when the driving voltages are applied to the plurality of display pixels in the electronic paper display device.

4. The system of claim **1**, wherein the page transition display system comprises:

a committed palette list, the committed palette list comprising one or more frame regions that are being updated, the one or more waveforms for driving the plurality of display pixels in a display update region corresponding to a frame region, and at least one subframe and at least one cycle number of the waveform table at which the update to the display update region would be complete; and

wherein the page transition display system is further configured to, once the control signals are generated, remove from the committed palette list the one or more frame regions and the one or more waveforms associated with the display update region.

5. The system of claim **1**, further comprising:

a subframe buffer coupled to the subframe producer, the subframe buffer configured to receive the one or more subframes from the subframe producer, store the one or more subframes and send the one or more subframes to the display subsystem.

6. The system of claim **1**, wherein the page transition display system is configured to identify the waveform associated with a transition matrix pixel by accessing an entry in the waveform table based on a subset of bits comprising the transition matrix pixel.

7. A method for modifying a plurality of display pixels in an electronic paper display device comprising:

responsive to receiving a first display request, determining whether a subframe buffer is full;

responsive to determining that the subframe buffer is not full, updating a subframe counter;

generating a first subframe associating one or more waveforms with a plurality of transition matrix pixels by processing the plurality of transition matrix pixels in parallel to identify the one or more waveforms from a waveform table for modifying the plurality of display pixels in the electronic paper display device associated with the plurality of transition matrix pixels, the first subframe including a part of a waveform for driving one of the plurality of display pixels in the electronic paper display device, wherein processing the plurality of transition matrix pixels includes:

loading the plurality of transition matrix pixels into a plurality of positions in an input register;

generating data in a holding register by selecting the data from a lookup table based on at least two subsets of the plurality of transition matrix pixels loaded at different positions in the input register; and identifying the one or more waveforms from the waveform table using the data in the holding register;

generating control signals associated with the one or more waveforms, the control signals identifying the plurality of display pixels in the electronic paper display device associated with the plurality of transition matrix pixels and driving voltages for application to the plurality of display pixels; and

applying the driving voltages to the plurality of display pixels.

8. The method of claim **7**, wherein generating the first subframe associating the one or more waveforms with the plurality of transition matrix pixels further comprises:

storing the first subframe in the subframe buffer.

9. The method of claim **7**, further comprising:

determining whether the first subframe is the last subframe for modifying the plurality of display pixels in the electronic paper display device; and

responsive to determining that the first subframe is the last subframe for modifying the plurality of display pixels in the electronic paper display device, monitoring for a second display request.

10. The method of claim **9**, further comprising:

responsive to determining that the first subframe is not the last subframe for modifying the plurality of display pixels in the electronic paper display device, determining whether the subframe buffer is full;

responsive to determining that the subframe buffer is not full, updating the subframe counter;

generating a second subframe associating one or more waveforms with the plurality of transition matrix pixels by processing the plurality of transition matrix pixels in parallel to identify the one or more waveforms from the waveform table for modifying the plurality of display pixels in the electronic paper display device associated with the plurality of transition matrix pixels; and

storing the second subframe in the subframe buffer.

11. The method of claim **7**, wherein generating the first subframe comprises:

applying one or more single instruction multiple-data (SIMD) instructions to a vector including the plurality of transition matrix pixels to identify a waveform associated with each of the plurality of transition matrix pixels.

12. The method of claim **7**, wherein the plurality of transition matrix pixels from a same image are processed in parallel.

13. The method of claim **7**, wherein processing the plurality of transition matrix pixels further comprises:

applying a masking operation to the data in the holding register.

14. The method of claim **13**, wherein the masking operation is based on a subset of the plurality of transition matrix pixels from the input register that is different from the at least two subsets of the plurality of transition matrix pixels used in generating the data in the holding register.

15. A computer program product comprising a non-transitory computer usable storage medium including a computer readable program, the computer readable program when executed by a processor causes the processor to:

determine whether a subframe buffer is full responsive to receiving a first display request;

update a subframe counter responsive to determining that the subframe buffer is not full;

generate a first subframe associating one or more waveforms with a plurality of transition matrix pixels by processing the plurality of transition matrix pixels in parallel to identify the one or more waveforms from a waveform table for modifying a plurality of display pixels in an electronic paper display device associated with the plurality of transition matrix pixels, the first subframe including a part of a waveform for driving one of the plurality of display pixels in the electronic paper display device, wherein processing the plurality of transition matrix pixels includes:

loading the plurality of transition matrix pixels into a plurality of positions in an input register;

generating data in a holding register by selecting the data from a lookup table based on at least two subsets of the plurality of transition matrix pixels loaded at different positions in the input register; and

identifying the one or more waveforms from the waveform table using the data in the holding register; and

generate control signals associated with the one or more waveforms, the control signals identifying the plurality of display pixels in the electronic paper display device associated with the plurality of transition matrix pixels and driving voltages for application to the plurality of display pixels.

16. The computer program product of claim **15**, wherein to generate the first subframe associating the one or more waveforms with the plurality of transition matrix pixels, the computer readable program further causes the processor to store the first subframe in the subframe buffer.

17. The computer program product of claim **16**, wherein the computer readable program further causes the processor to:

determine whether the first subframe is the last subframe for modifying the plurality of display pixels in the electronic paper display device; and

monitor for a second display request responsive to determining that the first subframe is the last subframe for modifying the plurality of display pixels in the electronic paper display device.

18. The computer program product of claim **17**, wherein the computer readable program further causes the processor to:

determine whether the subframe buffer is full responsive to determining that the first subframe is not the last subframe for modifying the plurality of display pixels in the electronic paper display device;

update the subframe counter responsive to determining that the subframe buffer is not full;

generate a second subframe associating one or more waveforms with the plurality of transition matrix pixels by processing the plurality of transition matrix pixels in parallel to identify the one or more waveforms from the waveform table for modifying the plurality of display pixels in the electronic paper display device associated with the plurality of transition matrix pixels; and

store the second subframe in the subframe buffer.

19. The computer program product of claim **15**, wherein to generate the first subframe, the computer readable program further causes the processor to apply one or more single instruction multiple-data (SIMD) instructions to a vector including the plurality of transition matrix pixels to identify a waveform associated with each of the transition matrix pixels.

20. The system of claim **1**, wherein the waveform table is an indexed storage for the one or more waveforms, and wherein the indices in the waveform table are not permanently committed to a particular waveform and the indices are updated repeatedly with different waveforms for driving the plurality of display pixels in the electronic paper display device to a color.

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